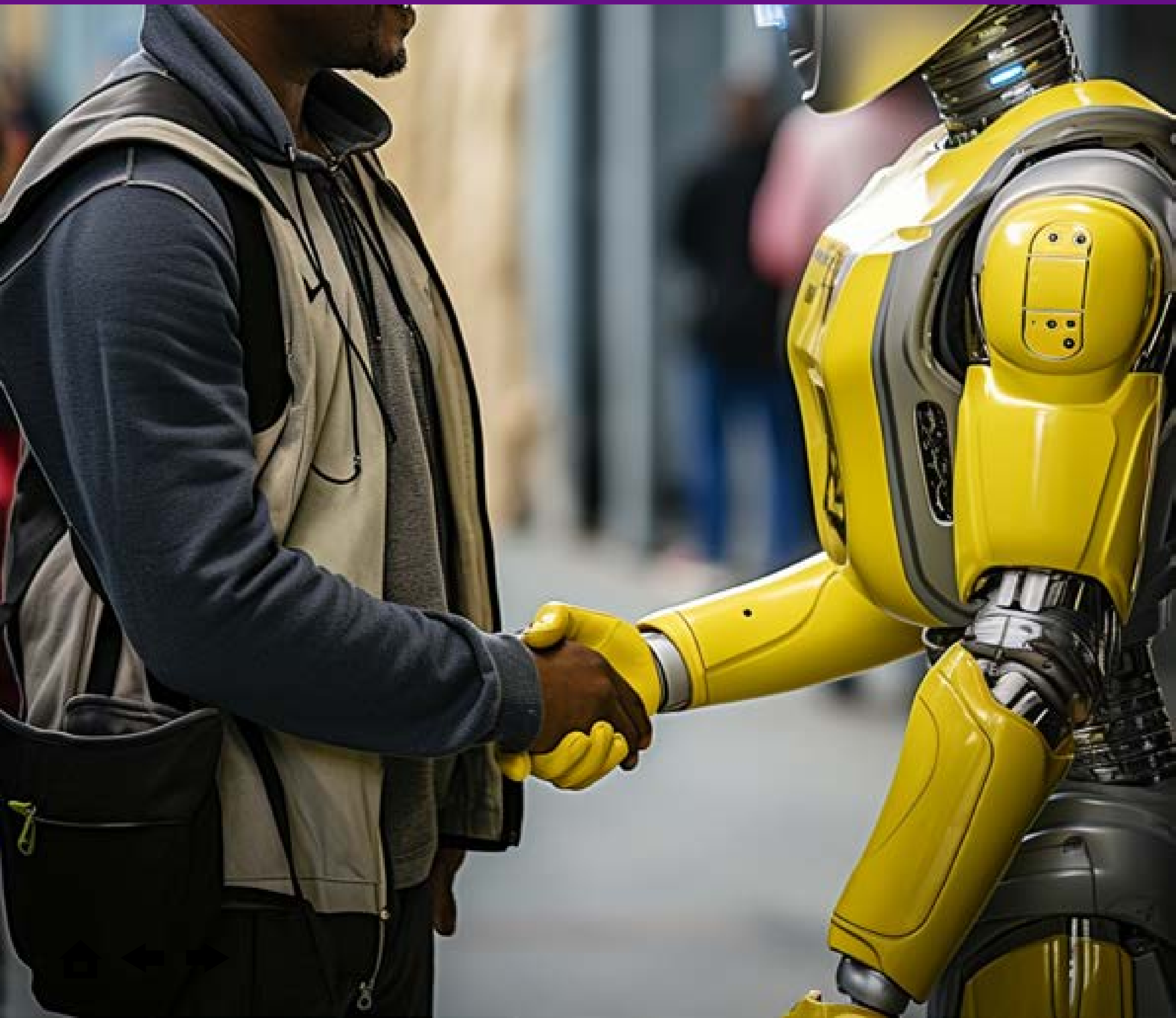
SECTION
2
ROBOTS AND SOCIETY 1



Principles of Robotic Systems

Robots and Society

INTRODUCTION

This section focuses on robots and how they operate. You will explore the key differences between robotic and non-robotic systems and uncover the essential building blocks that make robots work. You will also look at the interconnected subsystems like sensors, actuators, and control systems that allow robots to perceive their environment, make decisions, and perform tasks. This section will also examine robot control systems, differentiating between feedback and non-feedback loops. By the end, learners will be able to classify these systems and proficiently use logic and loop diagrams in designing robot control systems. Knowledge from this section will help you explain how everyday appliances like air conditioners, toasters and motion sensor lights operates.

At the end of this section, you will be able to:

- Assess various systems and classify whether they fall under robotic or non-robotic systems and outline the functions of the subsystems of robots.
- Classify feedback and non-feedback loop systems and demonstrate the use of logic and loop diagrams in control systems design
- Describe robots and identify the differences between robotic and non-robotic systems.
- Describe the attributes and functionalities of a robot's subsystems and how they interconnect.
- Contrast non-feedback loop systems and feedback loop systems.
- Evaluate the use of logic and loop diagrams and demonstrate their use in control systems' design.

Key Ideas

- Robots are autonomous machines that can assist humans in a variety of tasks. They are programmed to perform complex operations.
- Robots are typically composed of mechanical, electrical, and computational components that work together to enable their functionalities.
- The key features of a robot include autonomy, programmability, sensing and perception, mobility and interactivity.
- Robotic systems are not only made up of single robots but also include additional components such as controllers, communication interfaces, software systems and multiple robots working together or in coordination with other external systems.
- Robotic systems have sensors and actuators that execute tasks autonomously or semi-autonomously, while non-robotic systems require human intervention for operation.

- Sensors and actuators allow robots to interact with their environment. Their control system processes information from the sensors and makes decisions, which are then carried out by the actuators, all powered power supply units (subsystems).
- A robot relies on interconnected subsystems for autonomy and task execution. The key subsystems of a robotic system are the sensing subsystem, the control subsystem, the actuation subsystem and the power subsystem.
- A control system is a collection of mechanical or electronic components that directs, instructs, controls or monitors the actions of other systems, devices, or processes.
- Control systems are essential in regulating processes and ensuring desired outcomes in the functioning of robots. Two major control systems of robots are the feedback loop and the non-feedback loop.
- A feedback loop is a control system that incorporates a feedback mechanism to continuously monitor and adjust output based on a comparison with a desired value or reference input.
- Non-feedback loop systems are control systems where the output does not influence or affect the control action.
- Loop diagrams, also known as control loop diagrams or process loop diagrams, are visual representations that show flow directions and the interaction of components in a control system
- In a control loop, various sensors gather data, process it, and if modification is required make adjustments to keep the control process operating the way it should.
- Logic diagrams in control systems are used to represent the logical sequence of operations in the system. They show how different components and functions are logically connected to achieve the desired control action.
- Control systems are important in robotics because they determine how the robot operates. The way a robotic arm moves or a machine that can navigate a maze autonomously—this is where control system design comes into play.

ROBOTS, ROBOTICS SYSTEMS AND NON-ROBOTIC SYSTEMS

Robotic systems and non-robotic systems may be similar, but in real-case situations they are not. This material is developed to help you acquire knowledge of robots, robot systems and non-robotic systems. Robots rely on interconnected subsystems for autonomy and task execution. You will explore key components such as sensing, actuation, control, and power systems. Knowing these subsystems helps you to understand how robots perceive their environment, make decisions, and perform physical actions. Here, the differences between robotic and non-robotic systems, their roles and applications, as well as their attributes (characteristics) and functionalities of a robot's subsystems and how they interconnect are considered.

Robots

The term "robot" was first used in the early 1900s by Karel Čapek, a Czech playwright, in his play "R.U.R." or "Rossum's Universal Robots." In the play, robots were manufactured by humans and heartlessly exploited by factory owners until they revolted and ultimately destroyed humanity. In Czech, the word "robot" translates to "worker" or "servant."

In today's world, a robot is a machine designed to perform tasks automatically or with minimal human intervention. Typically, robots are programmable devices that can conduct a variety of actions or movements based on predefined instructions.

Robots are typically composed of mechanical, electrical, and computational components that work together to enable their functionalities. These components are clearly the results of advancements from the first, second and third industrial revolutions, respectively. Currently, many robots incorporate technological advancements from the Fourth Industrial Revolution, including artificial intelligence and connectivity.

Key Features of Robots

The following are the distinctive features of Robots:

1. Autonomy

Robots can operate independently or semi-independently, executing tasks without continuous human intervention. This is the evidence of basic intelligence, but not in the same way as human intelligence operates.

2. Programmability

Robots can be programmed to perform a wide range of tasks, allowing flexibility and adaptability in their functions.

3. Sensing and perception

Robots are equipped with sensors to perceive their environment, enabling them to gather information and make decisions based on their surroundings.

4. Mobility

Many robots can move or manipulate objects in their environment, either through locomotion or manipulation mechanisms.

5. Interactivity

Robots often interact with humans and/or their environment in various ways. They can receive input or commands from humans and/or their environment through interfaces such as touch screens, voice recognition, or gesture recognition. They can also provide output or feedback through displays, speech, or other forms of communication.

Robotic Systems

Robotic systems are defined as systems that provide intelligent services and information by interacting with their environment, including human beings, via the use of various sensors, actuators, and human interfaces. They are essentially machines called robots that replicate or substitute for human actions.

It is common for people to use the terms “robots” and “robotic systems” interchangeably, especially in casual conversation or general discussion. However, technically speaking, there is a distinction between the two.

A robotic system is a more complex arrangement designed to achieve specific objectives efficiently by integrating robots with additional elements to perform interconnected tasks or functions. In other words, Robotic systems are not only made up of single robots but also include additional components such as controllers, communication interfaces, software systems and multiple robots working together or in coordination with other external systems.

Robotic systems inherently have all the distinctive features of robots in addition to the features of the systems they integrate.

Robotic systems consist of three (3) main components:

1. Mechanical Construction

A frame, form, or shape designed to achieve a particular task. For example, a robot designed to travel across heavy dirt or mud might use caterpillar tracks.

Click the link below to watch a video of a Robotic arm performing varied tasks

2. Electrical components

Robots need electrical components that control and power the machinery. For example, an electric current—a battery, for example—is needed to power most robots.

3. Software programme

Robots contain at least some level of computer programming. Without a set of codes to instruct it on what to do, a robot would just be another piece of simple machinery. Inserting a programme into a robot gives it the ability to know when and how to carry out a task.

Integration of Robotic systems

Robotic Systems have been integrated in some environments in the following ways:

i. Manufacturing industry

Robotic arms and automated assembly lines are extensively used in manufacturing plants to perform tasks such as welding, painting, assembly, and packaging. These robotic systems may consist of robotic arms, conveyor belts, sensors, controllers, communication modules, etc.

https://youtu.be/wHVmXiI5rCE?si=Lf5KpA6mWD8sPwXZ

ii. Healthcare facilities

Surgical robots assist surgeons in performing minimally invasive surgeries with greater precision and control. They can also automate repetitive tasks like medication dispensing, sterilisation, and patient transportation, improving patient outcomes and reducing healthcare worker strain. The automated Medication Dispensers may incorporate robotic mechanisms and medication management software for accurate dosing and dispensing. Also, the Surgical Robotic Systems may integrate robotic arms, end-effectors, cameras, a database of approved surgical methods, artificial intelligence models and control consoles for precise surgical procedures.

Fig. 2.1 Da Vinci robot surgeon performing keyhole (laparoscopic) surgery, a remote-controlled surgical system, developed and produced by the US company Intuitive Surgical.

iii. Agriculture

Agricultural robotic systems, such as Precision Farm Drones and autonomous tractors, help farmers monitor crops, apply fertilisers and pesticides, and harvest produce. These robotic systems increase efficiency, optimise resource usage, and enable precision agriculture practices for higher yields and reduced environmental impact. The Precision Farm Drones are usually equipped with cameras, sensors, GPS modules, and communication systems. Also, the autonomous tractors integrate GPS guidance systems, sensors, actuators, communication systems and controllers for automated farming tasks.

Fig. 2.2 A self-driving tractor sows cotton seeds in the field at Yaha Township of Kuqa County, northwest China's Xinjiang Uygur Autonomous Region, March 23, 2018. The smart tractor, with automatic navigation system, can do farm work itself including ploughing and seeding.

iv. Transportation

Autonomous vehicles and drones are revolutionising transportation by providing safer, more efficient, and environmentally friendly mobility solutions. Robotic systems in transportation play roles in tasks such as delivery, surveillance, mapping, and maintenance. These autonomous vehicles would usually integrate the following Incorporate sensors (e.g., LiDAR, cameras), GPS receivers, actuators, communication modules, access to real-time traffic information and onboard computers for self-driving capabilities.

Click the link below to watch a video of a fully self-driving car.

https://youtu.be/tlThdr3O5Qo?si=B6-y4_SXfhebVyt-

What is a Non-Robotic System?

A non-robotic system is a system that uses human effort, mechanical machinery, or some automated system without the advanced capabilities of robots. It may have some of the features of robots, such as autonomy, sensing, and decision-making, but not all the combined features of robots are present.

Non-robotic systems are typically designed for specific purposes and have limited interaction with the environment.

Examples of non-robotic systems are given below.

Non-robotic automated systems

Non-robotic systems perform pre-programmed tasks but lack the adaptability and autonomy associated with robotic systems. A typical example of such automated systems is the Automated Teller Machine (ATM). While ATMs automate certain banking transactions such as cash withdrawals, deposits, and balance inquiries, they do not incorporate all the features of robots. They lack robotic features such as autonomy, decision-making, or sensing.

Other examples of non-robotic automated systems include vending machines, automatic doors, automatic conveyor belt systems, automatic car washers, self-service kiosks, elevators, lifts, etc.

i. Mechanised systems

Mechanised systems involve the use of machinery or mechanical devices to aid in specific tasks. They are typically controlled by human operators and do not possess the autonomous decision-making capabilities found in robotic systems. Some examples include vehicles, lawnmowers, combine harvesters, escalators, etc.

ii. Computerised systems

Computerised systems are not necessarily considered robotic systems because they lack physical manipulation capabilities and autonomy, which are defining characteristics of robots. While computerised systems may automate certain processes or tasks using software and electronic controls, they do not typically involve physical actuators or robotic arms to interact with the environment. Instead, computerised systems rely on algorithms, sensors, and digital interfaces to execute predefined instructions or commands. Some examples of computerised systems, which are non-robotic systems, include Traffic Light Control Systems, calculators, chatbots, web crawlers, Point-of-Sale (POS) Systems, Home Security Systems, Automated Inventory Management Systems, etc.

iii. Control systems

Control systems are not considered robotic systems because they primarily focus on regulating and coordinating the operation of mechanical or electronic components without direct physical manipulation of the environment. While control systems may automate processes and provide feedback mechanisms to adjust parameters based on predefined criteria, they typically do not involve the integration of robotic actuators or manipulators for interacting with objects or performing tasks autonomously. Examples include Heating, Ventilation and Air Conditioning (HVAC) Systems, Industrial Process Control Systems, Water Level

Control Systems, Aircraft Autopilot Systems, Speed Control Systems, Missile Guidance Systems, etc.

Activity 2.1

1. **Designing Your Dream Robot**
   Design your dream robot using readily available materials such as pen, pencil, paper, cardboard, etc. Label the parts of your designed robot and add a description on a separate sheet explaining what your robot does.
2. Discuss different systems in groups and sort them into either Robotic or Non-Robotic Systems. Give justification for your classification. Share your findings with other groups.

SUBSYSTEMS OF A ROBOT

Robots rely on interconnected subsystems for autonomy and task execution. This section explores key components such as sensing, actuation, control, and power systems. Knowing these subsystems helps you understand how robots perceive their environment, make decisions, and perform physical actions

Subsystems of a Robot

Robotic subsystems are the fundamental components that make up a robot. They work together to enable the robot to function effectively. Robots encompass various subsystems that enable their autonomy and task performance. These subsystems work together in a coordinated manner to enable the robot to perform tasks and interact with the environment.

After the robot has been powered using the **power subsystem**, the **sensing subsystem** perceives the environment, providing feedback to the **control subsystem**. The control subsystem processes the sensor data, makes decisions, and generates commands for the **actuating subsystem**. The actuating subsystem then actuates **effectors** to perform physical actions, allowing the robot to interact with objects and the surrounding environment.

Effectors are end tools attached to actuators. Examples of effectors include grippers, end-of-arm tooling (EOAT), vacuum suction cups, cutting tools, welding torches, spray nozzles, dispensing nozzles, etc.

This continuous loop of sensing, processing, and actuation facilitates the robot's functionality and enables it to complete tasks autonomously or under human guidance. By integrating these subsystems and ensuring their proper coordination, robots can adapt to varying conditions, navigate environments, manipulate objects, and perform complex tasks, enhancing their usefulness across various industries and applications.

The main subsystems of robots are:

i. The sensing subsystem

Like the sensory organs of the human body (such as eyes, ears, nose, and skin), the sensing subsystem of a robot perceives and collects information about the environment. A sensor is a device that detects a change in the environment and sends a signal to the processor for further action. Sensors such as cameras, LiDAR, proximity sensors, and touch sensors provide input that helps robots make informed decisions based on the data they gather.

ii. The control subsystem

Like the nervous system in humans, the control subsystem processes sensory information, makes decisions, and coordinates the actions of the robot's components. The control system governs the overall operation of the robot. It includes hardware and software components responsible for processing sensor data, generating control signals for the actuation system, and coordinating the robot's actions. The control system enables robots to make decisions and execute tasks based on their programmed instructions. It usually consists of a processor and channels through which it transmits data or instructions to other components or subsystems.

iii. Actuation subsystem

Comparable to the muscular system in humans, the actuating subsystem of a robot generates physical movements or actions based on commands from the control system. The actuation system provides robots with the capability to physically interact with the environment. It comprises motors, servos, hydraulics, or other mechanisms that generate motion and enable robots to manipulate objects, navigate their surroundings, or perform specific tasks.

iv. Power subsystem

Resembling the cardiovascular system in humans, the power subsystem provides energy to the other subsystems of the robot, enabling them to function and perform tasks. It may consist of batteries, fuel cells, or other power sources, along with the necessary circuits and distribution mechanisms to ensure the robot's proper functioning. The power subsystems supply electrical energy to the robot's actuators, sensors, and controllers, ensuring their proper functioning. They may also include mechanisms for recharging or replenishing energy sources.

Fig. 2.3: The subsystems of a robot

Activity 2.2

Fig. 2.4 Subsystems of a robotic vacuum cleaner ().

a. Carefully examine the provided technical description of a robot vacuum cleaner in Fig. 3.4 and classify each of its labelled parts under the robot's main subsystems (sensing, control, actuation, and power).

b. Provide justification for each category by briefly explaining why it belongs to that specific subsystem.

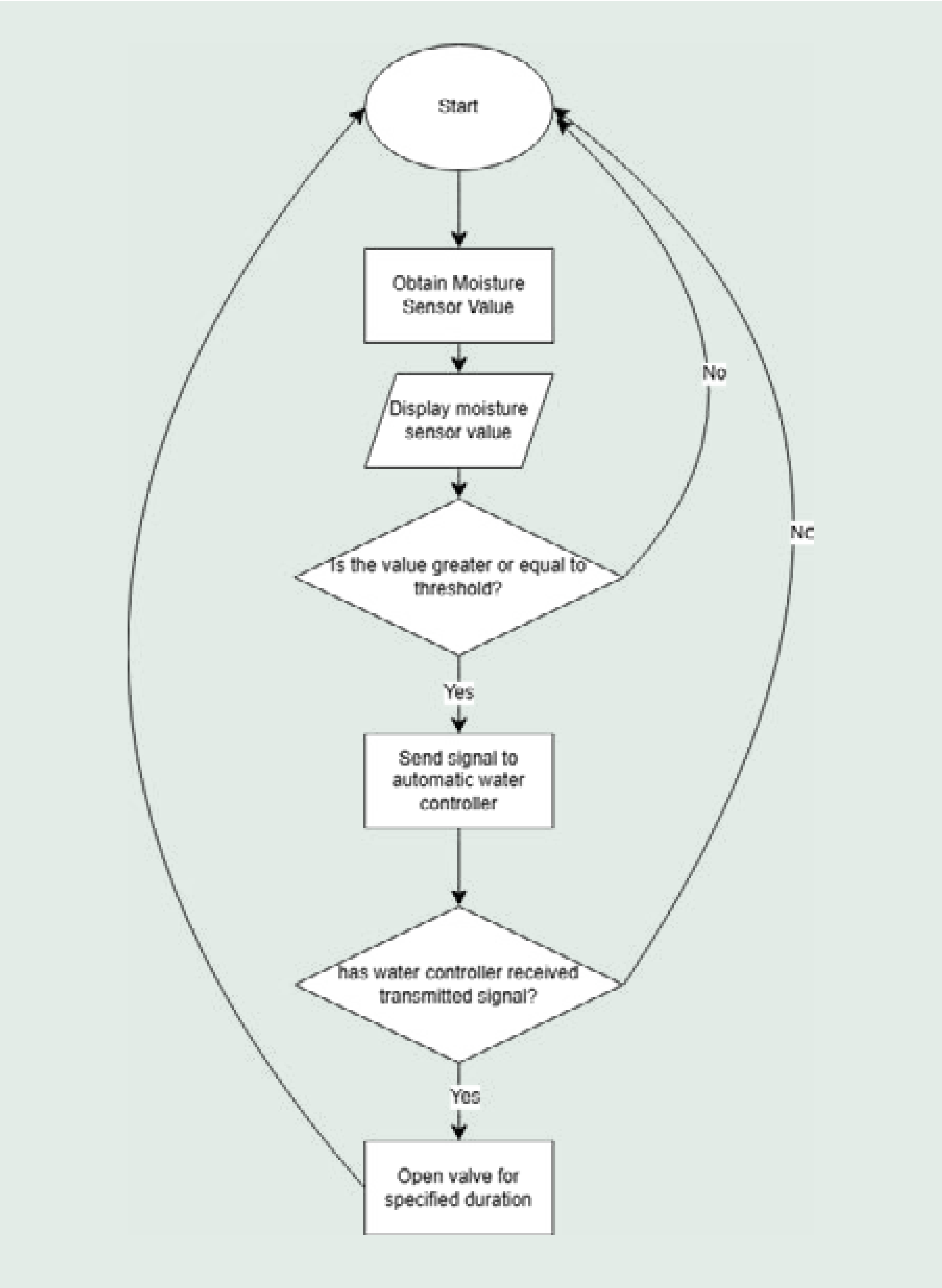
c. Present their results using at least one of the following methods:

   i. Chart/Table: Fill out a chart or table with columns for "Part Name," "Subsystem," and "Justification."

   ii. Annotated List: Create a list of parts with annotations beside each one, specifying its subsystem and justification.

   iii. Mind Map: Develop a mind map with the central theme "Robot Vacuum Cleaner Subsystems." Branch out from the centre, listing each subsystem and its corresponding parts with justifications.

   iv. Create a short presentation explaining the classification of parts and the role of each subsystem in the robot vacuum cleaner's operation.


Start
Obtain Moisture Sensor Value
Display moisture sensor value
Is the value greater or equal to threshold?
No
Yes
Send signal to automatic water controller
has water controller received transmitted signal?
No
Yes
Open valve for specified duration

FUNDAMENTALS OF CONTROL PRINCIPLES IN AUTOMATION AND ROBOTICS:

FEEDBACK AND NON-FEEDBACK LOOP SYSTEM

In the world of automation and robotics, control systems play a crucial role in ensuring machines operate efficiently and accurately. Control systems are essential in regulating processes and ensuring desired outcomes in the functioning of robots and machinery in general. Understanding the principles of control systems is essential for individuals interested in and want to further explore robotics and automation.

In this lesson, your teacher will help you to understand the fundamentals of control principles, focusing on the two main types of control systems; non-feedback loop and feedback loop control systems which are crucial aspects of robotics, automation, and process control. By the end of this section, you will be able to differentiate between feedback and non-feedback loop systems and to classify control systems effectively.

CONTROL SYSTEMS

A Control System is a collection of mechanical or electronic components that directs, instructs, controls, or monitors the actions of other systems, devices, or processes. A control system is made up of three main components: a sensor, a controller, and an actuator.

- The sensor detects a physical quantity such as temperature, pressure, or position, and converts it into an electrical signal.
- The controller processes this signal and generates an output signal used to control the actuator.
- The actuator is a device that translates the output signal from the controller into a physical action, such as opening or closing a valve, turning a motor on or off, or adjusting the speed of a motor.

Control systems in robotics are like the brains that help robots decide what to do and how to do it. These systems take in information (inputs), such as commands you might give or data from sensors, and then tell the robot how to respond (outputs). This could involve moving parts of the robot, starting, or stopping motors, or adjusting sensors.

Control systems allow robots to perform tasks by themselves, making sure that they act accurately and consistently.

Examples of control systems are:

1. **Automatic doors**: These systems use sensors to detect movement and open or close doors accordingly.
2. **Automatic sprinkler/irrigation systems**: They monitor soil moisture levels and adjust watering schedules to maintain optimal plant health and conserve water.
3. **Lighting systems with motion sensors**: These systems activate or deactivate lights by detecting motion in their vicinity.

There are two main types of control systems. They are:

1. Feedback loop control system (also known as closed-loop control system)
2. Non-feedback loop control system (also known as open loop control system)

Feedback Loop Control Systems

Feedback loop control systems, also known as closed-loop control systems, are control systems that incorporate a feedback mechanism to continuously monitor and adjust output based on a comparison with a desired value or reference input.

In feedback loop systems, the output is fed back and compared with the desired value, and any differences or errors are used to generate a corrective action to regulate and maintain the output at a desired level.

In robotics, a closed-loop control system refers to a system in which feedback from sensors is used to continuously monitor and adjust the robot's behaviour.

Imagine you have a robot that can move around a room. Now, let us say you want the robot to follow a line on the floor. How does the robot know if it is staying on the line or if it is drifting away?

This is where a closed-loop control system comes in. Think of it like this: the robot has a special sensor underneath it that can 'see' the line on the floor. This sensor sends information to the robot's brain, like how your eyes send information to your brain.

Now, the robot's brain is like a computer. It takes the information from the sensor and decides what the robot should do next. If the sensor detects that the robot is drifting away from the line, the brain tells the robot to adjust its wheels to get back on track. The robot keeps checking the sensor and adjusting it repeatedly, like a loop. That is why it is called a closed-loop control system. It is like the robot is always checking itself and making sure it is doing what it is supposed to be doing.

So, a closed loop control system in robotics is when a robot uses sensors to gather information about its surroundings and then uses that information to adjust its actions in real-time. It is like a smart robot that can stay on track and do its job effectively.

See demonstration: https://youtu.be/lnP32gzHdvI

Key Characteristics of Feedback Loop Control Systems

The table below shows the key characteristics of feedback loop control systems.

Table 2.1 Key characteristics of feedback loop control systems

Continuous monitoring	Feedback loop systems continuously monitor the output to compare it with a desired value or reference input.
Error detection	These systems detect errors or deviations between the system output for a given reference input and the desired output value for the same reference input.
Adjustment and error correction	Feedback loop systems generate corrective actions or adjustments based on the detected errors or deviations to regulate and maintain the output at desired levels. Systems that can dynamically adjust their behaviour based on feedback, allowing for self-correction and adaptation, are known as Self-correcting Systems.

Components of Feedback Loop Systems

Feedback loop systems, like any other system, consist of a set of components such as the reference input, error signal, control element, control signal, actuator, and the feedback signal.

Reference input

The reference input (or input for short) is a signal intended to drive a desired output value or set point that the feedback loop system aims to achieve. It is the input deliberately channelled through the system targeting a specific system's performance. The controller compares the actual output with an ideal expected output to the reference input and measures feedback(error) to generate the control signal.

Error signal

The error signal is the difference between the reference input and the feedback information. It represents the deviation or error between the desired (reference input) and actual system performance. The error signal serves as the basis for the controller to generate the appropriate control action.

Controller (control element)

In a feedback loop system, a controller is a crucial component responsible for processing the feedback received from sensors and determining the appropriate actions to achieve the desired outcome or setpoint. The controller acts as the "brain" of the system, making decisions based on the feedback it receives and sending commands to the system's actuators to adjust its behaviour accordingly. It receives information from the sensor and compares it to the desired output value with reference to the reference input. Based on this comparison, the controller generates a control signal or action that is sent to the actuator to adjust the plant's behaviour.

Control signal (manipulating variable)

The control signal is generated by the controller based on the comparison between the desired value and the feedback information. It represents the corrective action needed to regulate or adjust the plant's behaviour. The control signal is sent to the actuator to effect the necessary changes.

Actuator

The actuator is responsible for translating the control signal from the controller into physical action or manipulation. It could be a motor, a valve, a heating element, or any device that can modify the plant's state or behaviour.

Feedback Signal/Path

The feedback signal/path feeds the output of the actuator back to the controller. It provides information on the actual performance or output of the plant to compare with the desired value with respect to reference input. This feedback enables the controller to adjust and regulate the system.

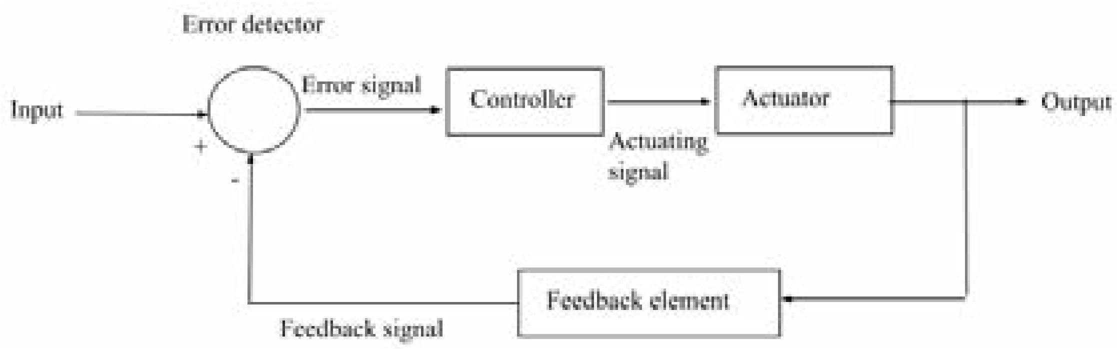


Fig. 2.5 The structure of a feedback loop control system.

Figure 2.5 illustrates a feedback loop control system (or closed loop control system). The reference input sets the desired output for the system. The sensor plays a critical role by continuously measuring the system's actual output. This measured value is fed back to the controller. The controller compares the actual output (feedback signal) with the desired output (reference input) to calculate the error signal. This error signal represents the difference between what the system is doing and what it is supposed to be doing. Based on this error, the controller generates a control signal that is sent to the actuator. The actuator translates this control signal into physical action, adjusting the system's behaviour to reduce the error and bring the actual output closer to the desired output.

This continuous cycle of measurement, comparison, adjustment, and measurement again ensures the system maintains the desired performance. By utilising feedback loops, systems can achieve stability, accuracy, and regulation of the desired output.

A Real-World Example of a Feedback Loop Control System

Figure 2.6 Air conditioner as a feedback loop control system

Imagine a home cooling system with a thermostat like an air conditioner. Air conditioners are devices designed to regulate indoor temperature and humidity levels, providing thermal comfort to the occupants. Air conditioners extract heat from the indoor air and transfer it to the outdoors, thereby cooling the interior space.

The thermostat (sensor) monitors the room temperature and compares it to the set point (desired temperature). If the room temperature is higher than the set point, the thermostat sends a signal to the air conditioner to turn on. The air conditioner cools the room, which causes the temperature to decrease. The thermostat continuously monitors the temperature and sends a signal to the air conditioner to adjust its output (cooling capacity) based on the room temperature. Once the room temperature reaches the set point, the thermostat sends a signal to the air conditioner to turn off or reduce its output.

This continuous process of monitoring, adjusting, and controlling the room temperature is a classic example of a negative feedback loop.

Non-Feedback Loop Systems

Non-feedback loop systems, also known as open-loop systems, are control systems where the output does not influence or affect the control action. In these systems, the control action or output is determined solely based on the input or pre-determined instructions without actively monitoring the output.

Non-feedback loop systems operate in a one-way fashion, where the output is not fed back for comparison or adjustment. Examples include electric bulbs, non-smart televisions, traffic light systems, etc.

Imagine a robotic arm that is programmed to pick up an object from a specific location **A** and move it to another location **B**. The robot is given a set of instructions (input) that include:

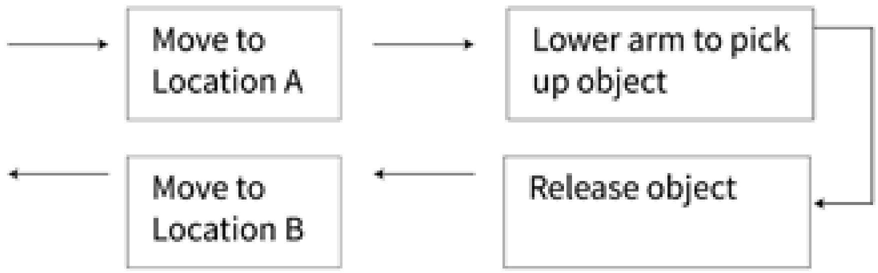


Figure 2.7 An illustration of a robot picking an object from location A to B.

The robot executes these instructions (process) without any feedback or monitoring (output) to ensure that the object has been successfully picked up or placed in the correct location. If the object is not in the expected location or the robot encounters an obstacle, the robot will not adjust its actions (no feedback loop) and may fail to complete the task.

In this scenario, the robotic arm is an example of an open-loop system/non-feedback loop system, as it does not use feedback to adjust its actions in real-time. This can lead to errors and inaccuracies, especially in complex or dynamic environments. Non-feedback loop systems are often used in robotics for simple, repetitive tasks where the output requirements are well-defined, and there is no need for continuous monitoring or adjustments based on feedback.

Key Characteristics of Non-feedback Loop Systems

Understanding the key characteristics of non-feedback or open-loop systems is crucial for designing and analysing control systems in various fields including engineering, robotics, and automation. You are going to explore the defining features of open-loop systems, including their lack of feedback, one-way communication, and limited adaptability.

The table below shows the characteristics of a non-feedback loop control system.

Table 2.2 Key characteristics of non-feedback or open loop control system

No feedback loop	There is no feedback from the output to the input to adjust the control action.
One-way communication	Information flows only in one direction, from input to output, without any return path.
No real-time monitoring	The system does not continuously monitor its output or performance.
No automatic adjustment	The system does not adjust its control action based on output or performance.
Pre-programmed instructions	The system follows a pre-defined set of instructions or algorithms without adapting to changing conditions.
No-self correctness	The system does not correct its errors or deviations from the desired output.
Limited adaptability	Open-loop systems are not very adaptable to changing conditions or unexpected disturbances.
Predictable output	The output is predictable based on the input and the pre-programmed instructions.

Components of Non-feedback or Open Loop Control Systems

i. Input

The signal or data that is sent to the system to start a certain operation or action is known as the input. It could be any other input data needed for the system to operate, or it could be a predetermined instruction with a set of parameters.

ii. Controller

The controller is in charge of interpreting the input and producing the control action following the preset guidelines. It controls the system's behavior and how it reacts to input. The controller can be implemented in many ways, including mechanical mechanisms, software algorithms, and electrical circuits.

iii. Actuators

Actuators are the parts that carry out the controller's instructions for the physical actions or operations. After receiving the control signals from the controller, they convert them into electrical impulses, mechanical motions, or other forms of energy needed to carry out the intended task.

iv. Output

The outcome or consequence of the system's operation, depending on the input and the control action, is known as the output. It may manifest as a motion, a signal that is generated, a particular output value, or any other output attribute that the system specifies.

Figure. 2.8 The structure of a non-feedback loop control system (Chandni et al, 2017)

Non-feedback loop control systems are commonly found in applications where the output requirements are well-defined, and there is no need for continuous monitoring or adjustments based on feedback.

Real-world example: A pop-up toaster

A pop-up toaster is a classic example of a non-feedback loop system. Here is a breakdown of its components and operation:

- *Input:* You place bread slices into the toaster (providing the initial input).
- *Controller:* The toaster has a built-in timer or a predetermined heating element setting (acting as the controller). This determines the toasting duration or level of heat applied.
- *Actuator:* The heating elements inside the toaster function as the actuator. They receive the "on" signal from the controller and generate heat.
- *Output:* The toasted bread (slightly browned and warm) is the final output.

A pop-up toaster is a typical example of a non-feedback loop system because the desired outcome is well-defined: toasting bread to a predetermined level of crispness. There is no need for the toaster to constantly monitor the bread's temperature and adjust the heating based on feedback. The timer or fixed heating element setting ensures consistent results (though slight variations might occur due to bread type or environmental factors).

Figure 2.9 A pop-up toaster as a non-feedback loop system.

EVALUATING LOGIC AND LOOP DIAGRAMS IN CONTROL SYSTEMS DESIGN

In designing robot control systems, logic plays a key role. Logic helps robots make decisions based on comparing collected data with the expected data. This is similar to how you solve puzzles by reasoning through the steps. So, you can see that logic is used in robotics for decision-making. It allows robots to evaluate situations based on a set of programmed rules and conditions. For example, if a robot is faced with an obstacle, logic can help it decide whether to go around it, over it, or turn back. Logic provides a clear set of instructions that the robot can follow to perform tasks.

To visualise how information flows and actions are coordinated within these systems, we use loop diagrams and logic diagrams. These are fundamental tools that help robots make decisions and perform tasks without constant human intervention.

Practical Application of a Logic Diagram

Imagine you are creating a smart light system for your bedroom. You want the light to turn on when you enter the room and turn off when you leave. Also, you want the light to stay off if it is already daylight.

To design this system, you will need to understand and use logic diagrams.

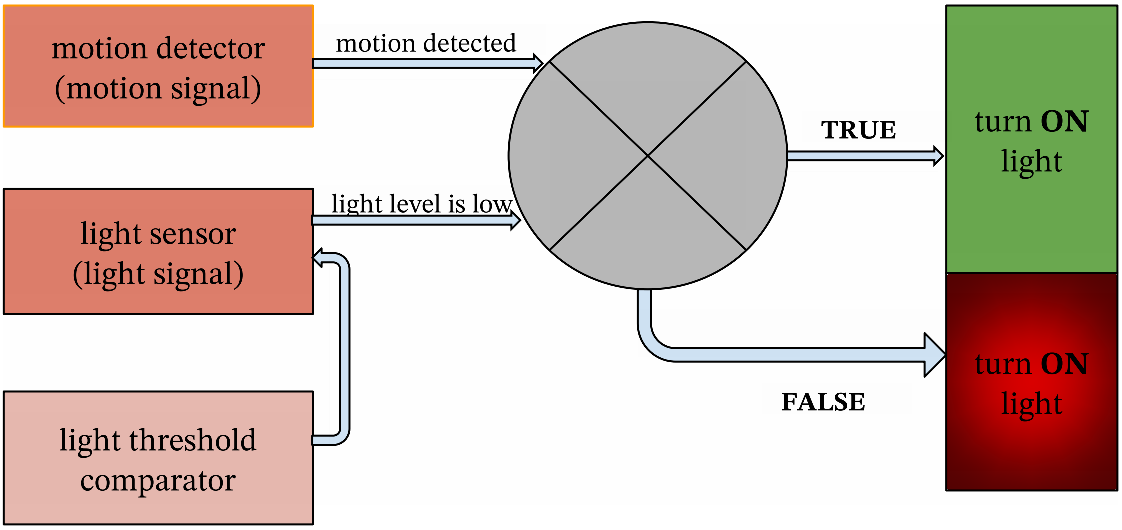


Figure 2.10

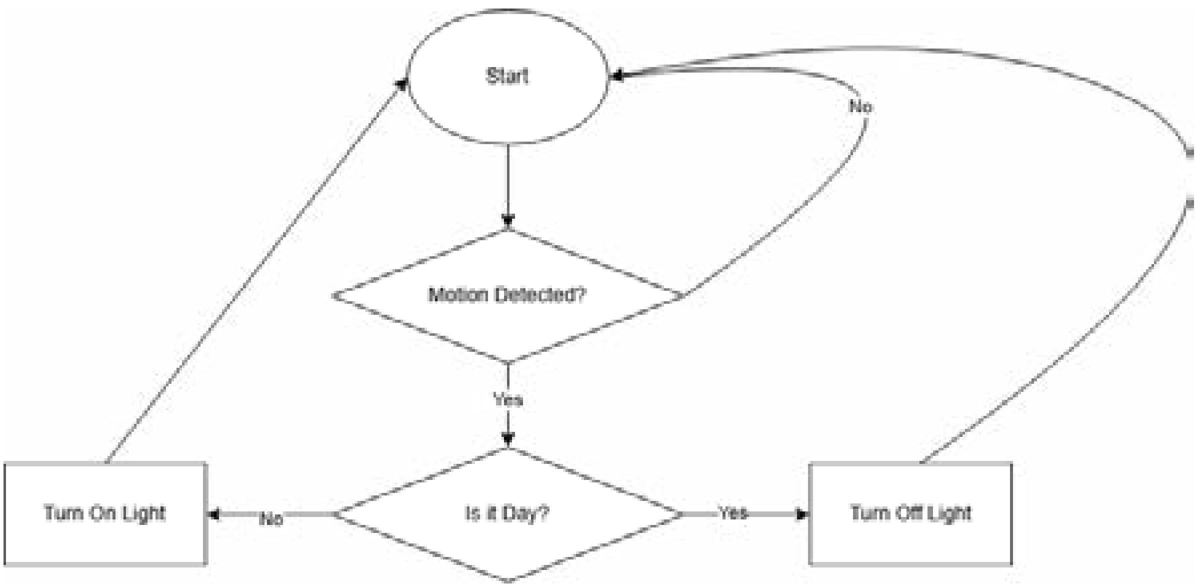


Fig. 2.11 Basic flowchart of a control system which regulates a motion sensory light

LOGIC DIAGRAMS

Logic diagrams are graphical representations that show how different inputs (like motion or light sensors) lead to specific outputs (like turning the light on or off). They represent logical relationships between variables, expressions, or operations. Think of them as visual guides that help you plan how a system will respond to different stimuli.

Some of the basic elements in logic diagrams may include Logic Gates, Symbols, Connections, Truth Tables and Composite Circuits.

Table 2.4: The various elements of a logic system and their descriptions

Elements in Logic Diagrams	Description
Logic Gates	A logic gate is a device that executes a logical operation performed on one or more binary inputs that produces a single binary output. These are the fundamental components that perform basic logical operations. These logical operations check/test the conditions of two or more statements before making a decision. Typical logic operations include AND, OR, NAND, NOR and XOR.
Symbols	Each type of logic gate and operation has a specific symbol to make the operation they perform easy to understand.
Connections	Lines connecting the symbols show how the inputs to logic gates interact to perform their logic operations.
Truth Tables	Truth tables are used to show how different combinations of inputs on the logic operator interact to produce specific outputs. In other words, it gives a relationship between input connections and the resulting outputs.
Composite Circuits	More complex systems use multiple inputs and outputs. This requires the combination of multiple logic gates to handle various logic conditions.

CONTROL LOGIC DIAGRAMS

A control logic diagram is a specialised type of logic diagram used to depict the control logic of a system, typically within the context of automation, machinery, or process control. These diagrams show how control elements like sensors, actuators, controllers, and other components interact to regulate and control the operation of a system.

Logic diagrams and control logic diagrams differ in their lines of operation. Logic diagrams focus on logical relationships and digital circuitry, but control logic diagrams emphasise control strategy and mechanisms for regulating system behaviour.

Components of a Control Logic Diagram

Some components of a control logic diagram are given below.

1. **Symbols:** Symbols in the control logic diagrams represent different control devices and components. Examples include shapes such as rectangles, circles, triangles, and diamonds. These symbols also have specific meanings. For example, rectangles may represent input or output devices.

2. **Connections:** A connection indicates the flow of control signals or logic between different components. Lines and arrows are used to connect the symbols. Every connection has its own representation.
3. **Control devices:** Sensors, motors, actuators and switches are typical control devices used in the control logic diagram. These devices are responsible for the measurement and control of variables within a control system.
4. **Logic elements:** They are the decision-making parts of control logic, or logic gates. They pick up inputs and give out reasonable outputs based on the meaning derived from the logic operation. Some examples include AND and OR gates and Programmable Logic Devices (PLDs).
5. **Sequential logic:** Sequential logic systems are designed to operate in sequential steps with the outputs depending on the current or previous state of the input. Examples of sequential logic elements are flip-flops, latches, state machines, and timing circuits. These elements enable the system to respond to changing conditions or events over time.
6. **Feedback loops:** Feedback loops regulate system behaviour and maintain desired set points or operating conditions. The output points are compared to the reference points in implementing the feedback loop. Feedback loops provide information about the system's output or performance, which is used to adjust control actions and/or maintain stability.
7. **Interlocks and safety systems:** Interlocks and Safety Systems are measures implemented in logic systems to avoid harmful situations. Although not all control logic diagrams have interlocks and safety systems, their inclusion may prevent hazardous conditions or protect equipment and personnel. Examples are pressure switches and alarms.

Representation of Control Logic Diagrams

Logic diagrams can be represented in several ways, each with its advantages and applications. Some common ways to represent logic diagrams include flowcharts, Ladder Diagrams (LDs), Karnaugh Maps (K-maps), State Diagrams and Truth Tables. However, this section discusses the use of flowcharts.

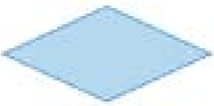
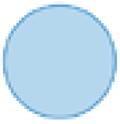
Flowchart diagrams

You already know that algorithms are a step-by-step logical approach to solving a problem or completing a task. Flowchart diagrams can also be used to represent the steps in an algorithm. In a flowchart diagram the steps are presented graphically using shapes and connecting lines. The shapes represent actions, decisions, inputs, and outputs. The connecting lines show the flows between and among the shapes. The connecting lines sometimes have arrows, which give the direction of flow.

So, in summary a flowchart is a powerful tool used in control system design to visually represent the decision-making process and the direction of flow in the system. It involves a visual representation of a process using symbols.

By connecting these symbols with arrows, flowcharts create a clear, step-by-step illustration of how a system operates logically.

Table 2.5: Basic flowchart symbols, names and their function

Symbol	Name	Function
	Start/End	Also known as the "Terminator Symbol," this symbol represents the start points, end points, and potential outcomes of a path. Often contains the description "Start" or "End" within the shape.
	Arrows	It is used to guide the viewer along their flowcharting path and the direction of flow of the logic being implemented.
	Input /output	Also referred to as the "Data Symbol," this shape represents data that is available for input or output as well as representing resources used or generated. While the paper tape symbol also represents input/output, it is outdated and no longer in common use for flowchart diagramming.
	Process	The process symbol is the most common component of a flowchart and indicates a step in the process.
	Decision	Indicates a question to be answered — usually yes/no or true/false. The flowchart path may then split off into different branches depending on the answer or consequences thereafter.
	Connector	Usually used within more complex charts, this symbol connects separate elements across one page.
	Annotations	It seeks to ask and answer questions among team members or communicate implementation details as a flowchart is developed.

Representation of a control system using a flowchart

To represent a control system with a flow chart, follow the steps below:

1. **Step 1:** *Define the problem*:

   When you are representing a system using a flowchart you start by identifying the control system's purpose.

   - What does the system control (is it temperature, water level, robot movement)?
   - What sensors does it use to gather information (e.g., temperature sensor, pressure gauge, camera)?
   - What actuators does it control to influence the system (e.g., heater, valve, motor)?

2. **Step 2:** *Identify inputs, processes, and outputs*
   Determine the inputs, the processes (controllers) and the desired outputs for the control system.

3. **Step 3:** *Develop the flowchart*
   Use the appropriate flowchart symbols to represent each step of the workflow of the control system. Connect the symbols with arrows to show the flow of execution.

   - Break down and list all the major steps involved in the process.
   - Arrange the steps in a logical sequence and identify any loops or repetition processes.
   - Use standard flowchart symbols to represent different elements.
   - Connect the symbols with arrows to show the flow of the process.
   - Label each process box with the correct action.
   - Label decision diamonds with conditional statements such as a "Yes" or "No" or "True" or "False.

4. **Step 4:** *Test the flowchart*
   Follow the flowchart step-by-step, to verify the logic and ensure that it produces the desired outputs for different scenarios.

Example Flowchart Design: An automated coffee-brewing machine making coffee

1. Switch ON
2. Sensor detects if the bean hopper is full
3. If the beans hopper is empty refill the beans hopper
4. If the beans hopper is full grind beans
5. If the water reservoir is full brew the coffee
6. If the water reservoir is not full, refill the water reservoir

7. Dispense the Coffee
8. Switch OFF

These actions can now be used to draw a flowchart by matching the action with the correct flowchart symbol. Read through the following to see how this has been done.

1. **Start**
   Switch ON. This will be represented by an oval shape since oval shapes represent the START of a process.
2. **Check if Bean Hopper is full**
   The weight of the bean hopper is compared to the full weight value. If it is full the next state is entered. If the bean hopper is not full, then the bean hopper is filled with coffee beans. Because it is a decision the diamond shape is used.
3. **Grind Beans**
   The coffee beans are ground and then the next state is entered. The rectangle is used to depict that this state of the operation is a process.
4. **Check if the Water Reservoir is full**
   The processor compares the volume of water in the reservoir to the full volume. This step involves a DECISION being made by the system and hence, it is presented by a 'Diamond' shape. If empty, refill the reservoir, if the reservoir is full then move to the next state.
5. **Brew Coffee**
   The coffee brewing process is initiated. This stage is represented with a process symbol.
6. **Dispense Coffee**
   The coffee is finally ready to be served.
7. **End**
   Switch OFF. This is represented by an oval shape since oval shapes represent the end of a process.

Putting the symbols together, the basic flowchart for the control system will be represented as in Figure 2.12.

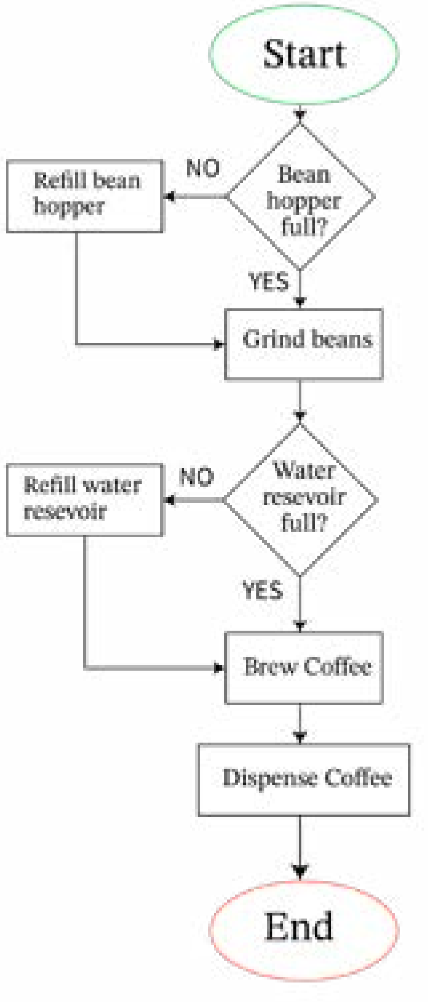


Fig. 2.12 Basic flowchart diagram for design of an automated coffee-brewing machine making coffee

LOOP DIAGRAMS

Loop diagrams provide a visual representation of the flow and interaction of components in a control system. They show the stages and steps in a loop, the flow of information, including measurements, error calculations, and control action, helping to visualise how a process is controlled.

The difference between a loop diagram and a flowchart is important. In a loop diagram the focus is on the iteration process. Iteration simply means 'repeating' and that is exactly what a loop does, it leads back to the start, so the process continues. A flowchart is a much more general tool which describes the flow or process of a system as a series of actions or steps.

There are two types of loop diagrams used in control systems. The open loop diagram and closed loop diagram.

The main difference between an open and closed loop diagram is **the presence of feedback**.

Open Loop

The system operates without feedback, meaning the output is not influenced by the input. It's simpler and known as a ***non-feedback system***. A household toaster is a good example of a non-feedback system because bread is toasted to a set time without any feedback on the condition of the bread. If the bread is dry and hard the set time might produce burnt toast.

Closed Loop

The system uses feedback to continuously adjust and optimise its operation based on the input, making it more stable and consistent. It is known as a ***feedback system***. A sensor controlled thermostat in a heating system is a great example of where feedback is used to continuously adjust and optimise the operation of the heater or air conditioner. You know that the thermostat uses a temperature sensor, and this monitors the room temperature and provides the feedback to switch the heater or cooler on.

Feedback and Non-Feedback Loop Diagram

1. A closed loop diagram for a control system

A closed loop control system regulates a system's behaviour based on ***feedback*** from its output, ensuring that it operates as close to the desired set point as possible. It functions to adjust itself to minimise errors that may occur.

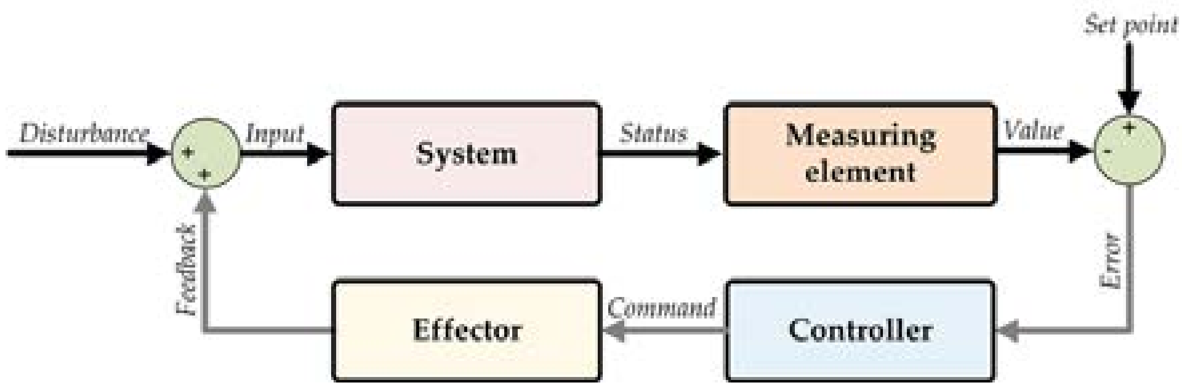


Fig. 2.13 A feedback loop control system

2. Open loop diagram for a control system

An open loop control system does ***not use feedback*** from the output to regulate or adjust the input. Instead, the system uses only the predetermined control actions based on the system's input or set point.

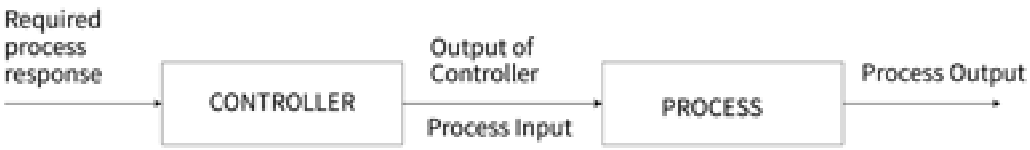


Figure 2.14: A non-feedback loop control system

Elements in Loop Diagrams

Each element used in a loop diagram has a meaning. Like flowcharts the elements are represented by shapes and lines.

These are the key elements in loop diagrams:

1. Blocks

Rectangular boxes represent system components such as sensors, controllers, actuators, and processes (plant).

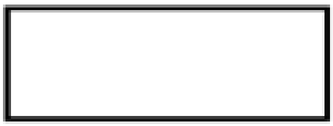


Fig. 2.15 Rectangular Block represents system components in a Loop Diagram

2. Lines

Lines indicate flow. Solid lines are used to represent the flow of information or control signals while dashed lines signify power connections.

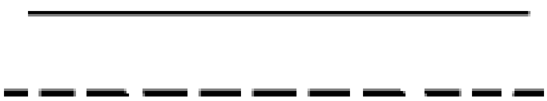


Fig. 2.16 Solid and Dashed Lines used in Loop Diagrams

3. Circular shapes

Circular shapes in loop diagrams are less common than rectangular blocks, but they are used to represent the following:

a. *Summation Point*: A circle with multiple lines entering it can represent a point where several signals are summed or averaged before proceeding further in the loop. This might be used, for example, to combine data from multiple temperature sensors in a building automation system.

b. *Logic Operation*: In some loop diagram notations, a circle can signify a logical operation like AND, OR, or NOT. This would be like how logic gates are represented in logic diagrams. For instance, a circle with "AND" written inside could indicate that two conditions need to be met (signals entering the circle) before a certain action is taken.

c. *Special Process*: Occasionally, a circle might be used to represent a specific process within the control loop that is too complex to depict with a simple block. This could be a mathematical function, a lookup table, or another sub-system with its internal workings. The circle would have a label explaining its function.

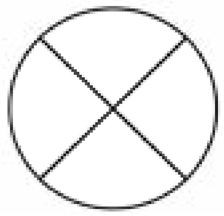


Fig. 2.17 Circular Shape used in a Loop Diagram.

What to consider when using Loop Diagrams to represent control systems

Consider the following when using Loop Diagrams:

1. Signal flow representation

Loop diagrams should clearly show the flow of signals within the loop, for example between different components, such as sensors, controllers, actuators, and from any power sources.

2. Feedback connections

The presence and proper representation of feedback connections in loop diagrams are crucial for understanding how the system adjusts and regulates its behaviour based on feedback information.

3. Clarity and completeness

Loop diagrams should be clear and complete, ensuring that all relevant components and connections within the control loop are accurately represented.

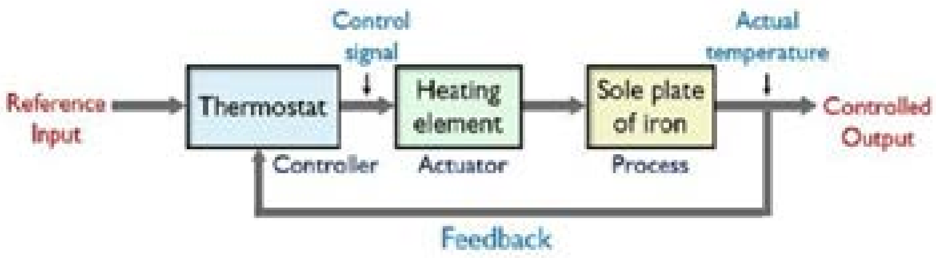


Fig. 2.18 A closed loop diagram of an automatic electric iron

Representation of a Control System using a Flowchart

Creating a logic diagram for a control system involves a series of steps to ensure accurate representation of the process and effective communication of the control logic. Here are the detailed steps:

Step 1: Gather Information about the Process

- Gain a thorough understanding of the process you are controlling. This includes the sequence of operations, conditions that initiate or terminate actions, and any safety or operational constraints. This is where you identify all the inputs (sensors) and outputs (actuators) involved in the process and clearly define the conditions under which the process starts, stops, or changes state.

Step 2: Identify the Specific Instruments Involved and Connect Them to the Control System

- Identify all the specific devices used in the process, such as sensors, actuators, controllers, and interfaces and understand how these instruments are connected to the control system, including wiring, signal types, and communication protocol.

Step 3: Choose the Appropriate Tool for the Design

- Decide on the tools you will use to create the logic diagram. Common tools include paper, pen, and pencil for initial drafts. Software tools like CAD programs, diagramming software (e.g., Microsoft Visio, Lucidchart), or specialised control system design softwares can be used for more complex design.

Step 4: Develop the Loop Diagram Layout

- Use standard symbols discussed above such as blocks, lines, and circular shapes to represent each instrument and component. Symbols should conform to industry standards (e.g., ISA-5.1 for instrumentation symbols). Draw connections between the symbols to illustrate the control logic. Use lines or arrows to indicate the flow of signals and actions. Label each symbol and connection clearly, indicating signal types, operational states, and any relevant details such as setpoints or thresholds.

Step 5: Maintain Clarity and Consistency

- Organise the diagram in a logical manner, ensuring that the flow of control is easy to follow from start to finish. Use consistent labelling conventions throughout the diagram. This includes using the same terminology, symbols, and abbreviations.

Step 6: Do a Peer Review with a Learner to Finalise the Design

- Present the logic diagram to a peer or learner who is familiar with the process but not directly involved in the design. This helps identify any unclear or ambiguous elements.

Activity 2.3

1. ***Follow the steps below*** to design a **loop diagram** to represent the control system for a home cooling system which regulates room temperature. Share and compare your diagrams with other learners.

   Step 1. Gather information about the process that is being controlled.

   Step 2. Identify the specific instruments involved and connect them to the control system.

   Step 3. Choose the appropriate tool for the design (paper, pen, pencil).

   Step 4. Develop the loop diagram layout i.e. using standard symbols to represent specific instruments and connecting them appropriately.

   Step 5. Maintain clarity and consistency i.e. ensure the diagrams are clearly labelled, and logically organised to show control flows.

   Step 6. Do a peer review with other learners to finalise the design.

Activity 2.4

1.

   A. Watch this simple video on how traffic light systems work at 4-way and a pelican crossing without pedestrians crossing the road. Here Two phase traffic signal Animated explanation || Traffic studies

   B. Under the supervision of your teacher, visit a nearby town with a traffic light system and observe how the traffic light system works.

   Precaution: Ensure road and traffic rules are strictly adhered to.

Activity 2.5

Design a flowchart and loop diagram for a basic traffic light control system for a pelican crossing with pedestrians crossing the road. [*This activity can be done as an individual or in group*].

Scenario

Imagine you are a traffic engineer responsible for designing a control system for traffic lights at a busy pelican crossing. Your goal is to ensure that vehicles from both directions can pass and also allow pedestrians to cross safely and efficiently, without causing traffic jams or accidents. To achieve this, you will design a flowchart and a loop diagram to outline the steps and logic the traffic light control system will follow.

The Traffic Flow

The intersection has 2 approaches labelled A and B to indicate the direction of vehicles, and direction C and D to indicate pedestrians crossing the road. Each approach can have a red, yellow, or green light, and the lights will change in a specific sequence to control the traffic flow.

Materials needed: Pen, pencil, paper

a. Follow the steps below to **design the flowchart** for the system
   Step 1: *Define the problem*
   Step 2: *Identify inputs, processes, and outputs*
   Step 3: *Develop the flowchart*
   Step 4: *Test the flowchart*

b. Follow the steps to design the **loop diagram** for the system.
   Step 1. Gather information about the process that is being controlled.
   Step 2. Identify the specific instruments involved and connect them to the control system.
   Step 3. Choose the appropriate tool for the design (paper, pen, pencil).
   Step 4. Develop the loop diagram layout i.e. using standard symbols to represent specific instruments and connecting them appropriately.
   Step 5. Maintain clarity and consistency i.e. ensure the diagrams are clearly labelled, and logically organised to show control flows.
   Step 6. Do a peer review with a learner to finalise the design.

Hint on system operation

- Start: This is where the system begins its operation.
- Initialise System: Set up initial conditions, such as turning on the system and setting all lights to red.
- Turn the green light on for approach A and B. At the same time, turn the red light on for approaches C, and D (for the pedestrians).
- Allow the green light for A and B to stay on for a set period (e.g., 30 seconds).
- Yellow Light for A and B.

Turn the yellow light on for approach A and B while keeping C, and D red.

- Allow the yellow light for **A and B** to stay on for a shorter period (e.g., 5 seconds).
- Switch the light from **yellow** to **red** for the approaches A and B for a short while (1 second) and turn green light for the pedestrian (approaches C and D).
- Wait and allow the green light for C and D to stay on for a while (15 seconds).
- Now, turn on the red light for the pedestrian (i.e. approaches C and D), at the same time turn on the **yellow** light for the vehicles from the approaches A and B and then wait for a short while like 5 seconds).
- The process begins by looping back to "Turn the green light on for approach A and B. At the same time, turn the red light on for approaches C, and D (for the pedestrians)".

Comparison of Non-Feedback and Feedback Loop Control Systems

The table below shows the key differences between non-feedback (open-loop) systems and feedback (closed-loop) systems in robotics and automation.

Table 2.3 Key differences between non-feedback (open loop) systems and feedback (closed loop) systems

FEATURE	NON-FEEDBACK LOOP CONTROL SYSTEMS	FEEDBACK LOOP CONTROL SYSTEMS
Definition	Systems that operate without checking their output.	Systems that adjust themselves by checking their output.
Response to Input	Direct response without considering changes in output or external conditions.	The response includes adjustments based on output and changes in conditions.
Complexity	Simpler design and operation.	More complex due to components like sensors and controllers.
Cost	Generally, less expensive due to simplicity.	More expensive due to additional components and technology.
Accuracy	Less accurate, potential for errors due to lack of adjustment to external factors.	Higher accuracy through continuous adjustment to conditions and outputs.
Use Cases	Suitable for applications where conditions are constant, and accuracy is less critical.	Ideal for applications requiring high precision and adaptability.

FEATURE	NON-FEEDBACK LOOP CONTROL SYSTEMS	FEEDBACK LOOP CONTROL SYSTEMS
Scenarios	These systems are best used where the input conditions are known and constant. For example, a non-feedback system is suitable for a conveyor belt in a controlled environment where the speed does not need to change once set	Feedback systems shine in environments where the output needs constant fine-tuning. These systems are crucial in scenarios where safety, precision, and adaptability to environmental changes are required.
Suitability	They are ideal for simple, cost-effective solutions in stable environments where the output does not need constant adjustment. Examples include electric heaters with a fixed operating time or simple automated lights in a room.	They are essential in complex and critical applications such as in medical devices like pacemakers, where the device must adapt to the patient's physiological conditions, or in automotive systems like anti-lock braking systems (ABS) which adjust braking force dynamically to prevent wheel lockup.
Example Applications	Basic household appliances like toasters, and simple lighting systems.	Thermostats, automatic pilots in aircraft, and industrial robotic arms.

Activity 2.6

1. In a group, select one of the following real-world scenarios that require a control system.
   - Automatically watering a potted plant
   - Automatically maintaining water temperature in a fish tank
   - Automatically regulating room temperature in an office space
   - Thoroughly blending powdery ingredients

   Identify if the selected scenario will require a feedback or non-feedback control system and provide justification.
2. As a group, design the selected control system to address the scenario using simple materials (cardboard and straws).

Extended Reading

- MIT OpenCourseWare - Introduction to Robotics:
- Lecture Notes | Introduction to Robotics | Mechanical Engineering | MIT OpenCourseWare

- Control system definition, types, and applications: https://www.electronicsforu.com/technology-trends/learn-electronics/control-system-definition-types-applications-and-faqs
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